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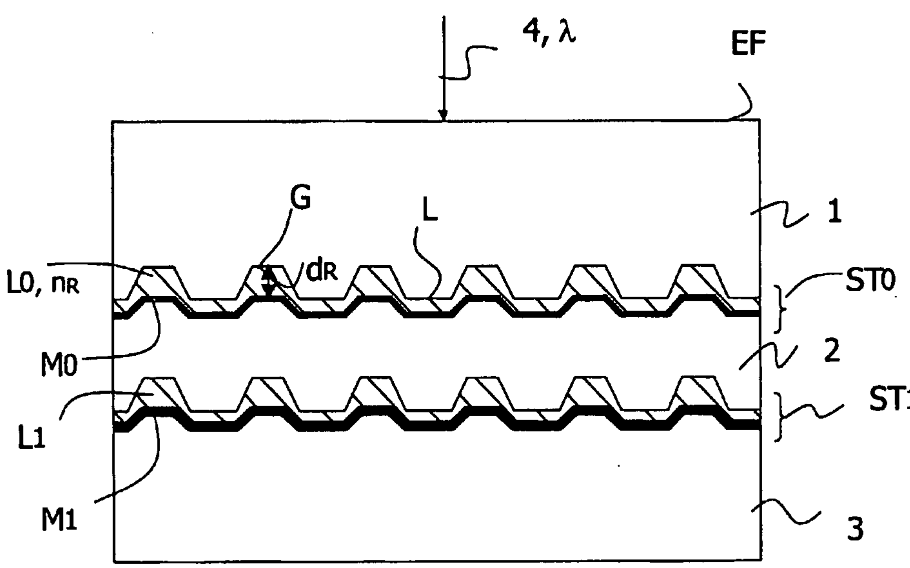
(54) Title: MULTI-STACK OPTICAL STORAGE MEDIUM



(57) Abstract: The invention relates to an optical storage medium comprising below an entrance face (EF) a higher recording stack (ST_0) comprising a higher recording layer (L_0) and at least a lower recording stack (ST_1), said lower recording stack (ST_1) being recorded or read back by a radiation beam (4) entering into the optical storage medium through the entrance face (EF) with a wavelength (λ), focused on said lower recording stack (ST_1) and transmitted through the higher recording stack (ST_0), a recording of the higher recording layer (L_0) causing an optical thickness variation between recorded and unrecorded areas of said first recording layer (L_0), which is included into the range [0.03λ, 0.125λ].

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MULTI-STACK OPTICAL STORAGE MEDIUM

DESCRIPTION

Field of the invention

The invention relates to a multi-stack optical storage medium. The invention also relates to a method of manufacturing such an optical storage medium.

The invention is particularly relevant for a dual-stack write-once optical storage medium using the DVD format.

Domain of the invention

Recently the Digital Versatile Disk (DVD) has gained market share as a medium with much higher data storage capacity than the CD. Presently, this format is available in a read-only (ROM), a recordable or a write-once (R) and a rewritable (RW) version.

A write-once or rewritable optical storage medium like a DVD comprises a recording stack comprising a recording layer. Recording of information in the optical storage medium occurs by locally modifying the optical properties of the recording layer with an intense laser beam. The recorded parts are usually referred to as pits or marks. An issue for both the write-once and the rewritable DVD format is the limited capacity and resulting recording time, because only single-stacked media are present with a maximum capacity of 4.7 GB.

A DVD-video, which is a ROM disk, dual-stack medium with 8.5 GB capacity, often referred to as DVD-9, already has a considerable market share, but information cannot be written on such DVDs.

Consequently, write-once DVDs with at least two stacks, which provide a capacity around 8.5 GB, are highly desired.

A problem raised by a dual-stack write-once optical storage medium is that the recording of data inevitably introduces local variations in the optical properties of the recording stacks. When accessing a recording stack through a written higher recording stack, the local variations in optical properties of the higher recording stack may deteriorate the focused optical beam used for reading and writing of the lower recording stack. If the aberrations introduced by the higher recording stack are too severe, writing and/or reading of the lower stacks may become impossible or of unacceptable quality.

Among the conditions which must be fulfilled by the stacks of the optical storage medium in order to limit the aberrations introduced by a higher recording stack to an

acceptable level, is a reduction of the phase difference of the light transmitted through written and unwritten parts of the higher recording stack.

Figs. 1a and 1b show an optical storage medium comprising a higher recording stack UST_0, RST_0 and a lower recording stack ST_1. The recording layer of the lower recording stack ST_1 is being recorded or read back by a laser beam 4, which is focused on said lower recording stack ST_1. Said laser beam 4 has a wave front 5, 7 and a focal spot 6, 8. In Fig. 1a, in which the higher recording stack UST_0 is unrecorded, the focused laser beam 4 does not present any aberration of its wave front 5 or focal spot 6. In Fig. 1b, in which the higher recording stack RST_0 contains recorded data, the focused laser beam 4 shows some aberrations in its wave front 7 and in its focal spot 8.

A write-once DVD (DVD-R) with two recording stacks is disclosed in the Japanese patent application published on the 13th of April 2001 with the publication number 2001-101709. Said recording stacks have a so-called MIM structure, which comprises a top thin metal recording layer M, an interference layer I, and another thin metal layer M. The solution proposed ensures that, using a focused laser beam with a wavelength λ, the phase difference of the light transmitted through written and unwritten parts of the higher recording stack is always less than 10 degrees or equivalently less than 0.02 times λ, which is obtained by making a recording layer sufficiently thin. For example, using a wavelength of 655 nm, the optical thickness of the first recording layer, which is equal to the product of the refractive index and the thickness of the first recording layer, must be less than 13 nm.

The main drawback of this solution is that the manufacture of such a thin metal recording layer is quite difficult.

Summary of the invention

The object of the invention is to provide a solution for implementing an optical storage medium with at least two recording stacks which is easier to manufacture.

This is achieved with an optical storage medium comprising on an entrance face a higher recording stack having a thickness d_R and a refractive index n_R and at least a lower recording stack, said lower recording stack being recorded or read back by a radiation beam entering the optical storage medium through the entrance face with a wavelength λ, focused on said lower recording stack, and transmitted through the higher recording stack, a recording of the higher recording layer causing an optical thickness variation $\Delta(n_R.d_R)$ between recorded and unrecorded areas of said first recording layer which lies within the range $[0.03\lambda, 0.125\lambda]$.

According to the invention, an optical storage medium is provided which ensures that, using a focused radiation beam with a wavelength λ, data recording of the higher recording layer will not modify optical properties of the radiation beam to such an extent that recording or reading back of a lower recording stack will be deteriorated. In particular, the optical storage medium in accordance with the invention ensures that the radiation beam is transmitted through a zone of the higher recording layer comprising recorded and unrecorded areas with a local wave front phase variation $\Delta\Phi$ which always remains within the range of $[0.03\lambda, 0.125\lambda]$. The higher recording layer has a thickness d_R and a refractive index n_R. In the optical storage medium in accordance with the invention, a recording of the higher recording layer causes a change of optical thickness, which is a product of said thickness d_R and said refractive index n_R of the higher recording layer. The local wave front phase variation $\Delta\Phi$ can be estimated by realizing that it is mainly the change in optical thickness $\Delta(n_R. d_R)$ of the higher recording layer that results in a phase difference in transmission. Thus, the following equation EQ_1 is obtained:

$$\Delta\Phi = \Delta(n_R. d_R) \approx \Delta n_R. d_R + n_R. \Delta d_R \qquad (EQ_1)$$

The higher recording layer comprises a recording material which is, for example, an organic dye material. It should be noted that for organic dye materials, data recording is mainly induced by a change (decrease) of the refractive index Δn_R. Therefore, equation EQ_1 reduces to equation EQ_{1B}:

$$\Delta\Phi = \Delta n_R. d_R \qquad (EQ_{1B})$$

In both cases, the condition imposed on $\Delta\Phi$ is fulfilled by choosing an appropriate thickness d_R of the higher recording layer.

If we consider a focused radiation beam having a wavelength λ being transmitted through a higher recording layer containing recorded data, the upper limit on $\Delta\Phi$ of 0.125λ can be derived as follows. The Maréchal criterion states that a focal spot remains "diffraction limited" if the root-mean-square (RMS) wave front error $We_{RMS} = \sqrt{|\langle \underline{W} \rangle^2 - \langle \underline{W^2} \rangle|}$ that is introduced by the local wave front phase variations $\Delta\Phi$ is less than 0.072λ. In a recorded area, a fraction x of the recording layer contains marks; typically $1/6 \leq x \leq 1/4$. When a wave front is transmitted through a recording layer containing recorded data, each recorded mark introduces a phase shift $\Delta\Phi$ to the part of the wave front that is incident on the mark. When averaged over the total wave front, the RMS wave front error becomes $We_{RMS} = \Delta\Phi.\sqrt{(x-x^2)}$.

A conservative estimate of the maximum allowed $\Delta\Phi$ is obtained by taking $x = 1/4$ and this results in $\Delta\Phi \leq 0.072\lambda/\sqrt{(3/16)}$, i.e. $\Delta\Phi \leq 0.125\lambda$. The lower limit for $\Delta\Phi$ is determined by considerations on modulation. Modulation stands for the maximum amplitude of the signals coming from the disc. Modulation of the signal is defined as the difference between the highest signal level and the lowest signal level, normalized by the highest signal level coming from the disk. For a recording material like an organic dye material, in which the refractive index is changed by a recording process, it turns out that when $\Delta\Phi$ is less than 0.03λ, the modulation becomes too weak for allowing a reliable read-back of the recorded disk.

It should be noted that the optical thickness $\Delta(n_R . d_R)$ of the higher recording layer is preferably chosen in the range of values $[0.05\lambda, 0.09\lambda]$, most preferably chosen in the range of values $[0.06\lambda, 0.08\lambda]$, for example equal to 0.073λ, because these values give the best compromise between modulation of the signal and local wave front phase variation.

A consequence of the above-mentioned condition for the local wave front phase change is that the higher recording layer of the optical storage medium in accordance with the invention does not need to be as thin as the one used in the MIM structure in accordance with the prior art. Said higher recording layer is thus easier to manufacture. Using, for example, an organic dye material having a refractive index of 2.2 in unrecorded areas and of 1.6 in recorded areas of the higher recording layer, an optical storage medium in accordance with the invention using the DVD format, that is with a radiation beam having a wavelength of approximately 655 nm, must have a higher recording layer thickness d_R in the range 28 nm $\leq d_R \leq$ 115 nm.

In a first embodiment of the invention, said higher recording layer (L_0) is made of an organic dye material. An advantage of the use of a higher recording layer made of an organic dye over a higher recording layer made of thin metal is that organic dyes require lower temperatures (200-300 °C) than thin metal films (at least 300-400°C) to achieve recording. Moreover, organic dyes have a very low heat conductivity, that is they lose their heat at a comparatively low rate, whereas metals have high heat conductivity and thus lose heat at a higher rate. The higher recording stack structure according to the first embodiment of the invention therefore requires a lower recording power than does the MIM stack structure. For example, at 1X speed, that is the standard speed of 3.49 m/s for DVDs, organic dye materials typically require less than 10 mW, whereas the MIM structure requires 12 mW. Said higher recording layer is therefore less power consuming, which is advantageous for portable applications.

In a second embodiment of the invention, the higher recording stack (ST_0) comprises a thin metal reflector layer (M_0). Compared with the MIM structure of the higher recording stack used in the prior art, only one thin metal layer is used in the optical storage medium in accordance with the second embodiment of the invention, which allows a higher transmission of the laser light, that is a greater fraction of light that can go through the higher recording stack and reach the lower recording stack.

In another embodiment of the invention, said thin metal layer is made of an Ag alloy, whereas the MIM structure comprises almost pure Au. The higher recording stack structure used by the optical storage medium in accordance with the invention is therefore cheaper.

Brief description of the drawings

The invention will be further described with reference to the accompanying drawings:

- Fig. 1a shows a laser beam focused on the lower recording layer and passing through the unrecorded higher recording layer of an optical storage medium,
- Fig. 1b shows a wave front aberration produced by a laser beam focused on the lower recording layer when passing through the higher recording layer of an optical storage medium, said higher recording layer comprising recorded data.
- Fig. 2 shows a schematic layout of a dual-stack optical storage medium according to the invention,
- Fig. 3a shows a detailed structure of the higher recording stack,
- Fig. 3b illustrates differences in optical path for light transmitted through an empty groove, an empty land, or a recorded groove of the higher recording layer,
- Figs. 4a and 4b show the optical constants of AZO and cyanine organic dye materials as functions of the wavelength,
- Fig. 5 shows the modulation as a function of the product of the refractive index variation and the thickness of the higher recording layer,
- Fig. 6 shows a diagram indicating jitter measurements of data read back from the lower recording layer through the partially recorded higher recording layer.

DETAILED DESCRIPTION OF THE INVENTION

An optical storage medium in accordance with the invention is shown in Fig. 2. Said optical storage medium comprises below an entrance face EF a substrate 1, a higher recording stack ST_0, a spacer layer 2, a lower recording stack ST_1, and a second substrate 3. The higher recording stack ST_0 comprises a higher recording layer L_0 and a thin metal

reflector layer M_0. The lower recording stack ST_1 comprises a lower recording layer L_1 and a thick metal reflector layer M_1.

In a first embodiment of the invention, the higher recording layer L_0 is made, for example, of organic dye having a refractive index n_R and a variation Δn_R of refractive index between unrecorded and recorded parts of the layer L_0. This is not limitative, however, because the higher recording layer L_0 may equally well be made of any recording material in which the recording process is based on a change in its refractive index.

It should be noted as well that, although in this embodiment of the invention the recording stack only comprises one recording layer L_0 and one thin metal layer M_0, the invention also applies to more complicated recording stacks.

Said organic dye material enables write-once data recording, as it is deteriorated by the recording process in such a way that data recording cannot be repeated. Consequently the first embodiment of the invention relates to a write-once optical storage medium. It should be noted, however, that the invention also concerns a rewritable optical storage medium, wherein the higher recording layer is made of a rewritable material, such that data recording causes a change in optical thickness of said rewritable material.

Fig. 3a shows the structure of the higher recording stack ST_0 in accordance with the first embodiment of the invention. The organic dye material is, for example AZO or cyanine dye. The higher recording layer L_0 is applied to the transparent pre-grooved substrate 1. The substrate 1 has a thickness value preferably lying within the range [0.30 mm, 1.2 mm], for example equal to 0.575 mm. It should be noted that a smaller range of authorized thickness values of [0.56 mm, 0.60 mm] is preferably used for DVDs.

The higher recording layer L_0 comprises grooves G and lands L. A groove G has, for example, a depth 10 of 160 nm and a width 15 of 320 nm. The distance between two grooves, also called track pitch 19, preferably equals 740 nm. The higher recording layer L_0 usually comprises at least two different values of its thickness d_R, which are a thickness on groove 13 of, for example, 60, 80, or 100 nm (upper limit is 115 nm), and a thickness on land 14 of 15, 25, or 40 nm. The thin metal layer M_0 has a thickness value 12 preferably in the range of [5 nm, 25 nm] and, for example, equal to 12 nm. An arrow 6 indicates the direction and position of the focused laser beam used for recording and reading the optical storage medium. For recordable DVDs, the focused laser beam has a wavelength λ approximately equal to 655 nm and a numerical aperture NA equal to 0.65. The transparent spacer layer 2 has a depth value substantially greater than the depth of focus of the focused radiation beam, which preferably lies within a range of [0.03 mm, 0.07 mm] and more preferably is equal to 0.05 mm.

An optical disc in accordance with the first embodiment of the invention may be manufactured as follows: the polycarbonate substrate 1 is molded by a stamper, which creates grooves G in the substrate 1. The organic dye material intended to form the higher recording layer L_0 is applied, for example, by means of spin-coating onto the pre-grooved substrate 1. Next, a semitransparent mirror made of silver alloy, called thin metal reflector layer M_0, is applied, for example by sputtering. On top of the thin metal layer M_0, a spacer layer 2 is fabricated by applying a UV-curable lacquer. The grooves G of the substrate 1 are replicated in the lacquer by pressing a stamper (for example of Zeonor). The lacquer is subsequently exposed to UV in order to cure it. On top of the grooves of the spacer layer 2, a new dye-based recording layer L_1 is applied. Next, a thick metal reflector layer M_1 is applied. The optical disc is finalized by gluing a dummy substrate 3 to the back of the thick metal layer.

An advantage of the use of a higher recording layer made of organic dye is that the organic dye can be applied by spin-coating, whereas the MIM structure requires additional sputter deposition steps for the interference layer and the thin metal recording layer. Spin-coating is easier to implement than sputtering. The fabrication procedure for the optical storage medium in accordance with the invention is therefore cheaper.

It is to be noted that the above-mentioned manufacturing method relates to dual-stack optical media, but that those skilled in the art should be able to derive a similar method for multi-stack optical media.

Fig. 3b shows the differences in optical path length transmitted through an empty groove 20, a land 21, and a recorded groove 22. In the case of a dye-based recording stack ST_0, the fact that the first recording layer L_0 comprises grooves and lands, also called leveling, introduces three different phases in transmission, which are a phase of land Φ_L of the focused optical beam 24 when passing trough a land 21, a phase of empty groove Φ_{GE} of the focused optical beam 23 when passing trough an empty groove 20, and a phase of recorded groove Φ_{GR} of the focused optical beam 25 when passing trough a recorded groove 25. The obtained phase differences are the following:

- $\Phi_{GE} - \Phi_{GR} = \Delta n_R.d_G$ (EQ_2), where d_G is the groove depth 13 and Δn_R the variation of the refractive index n_R of the dye-based recording layer.
- $\Phi_{GE} - \Phi_L = (n_R - n_0).(d_G - d_L)$ (EQ_3), where n_0 is the refractive index of the substrate 1 and d_L the land depth 14,
- $\Phi_L - \Phi_{GR} = \Delta n_R.d_G - (n_R - n_0).(d_G - d_L)$ (EQ_4).

Equation EQ_2 is equivalent to equation EQ_1. Another point is that a phase difference smaller than 0.125.λ is required for these three equations. However, with dye-based recording materials, $\Delta n_R \approx n_R - n_0$. Consequently, it turns out that the largest phase difference is given by equations EQ_1 and EQ_2, which means that only EQ_1 needs to be considered in the design of the first recording layer L_0.

Figs. 4a and 4b show the optical constants of two types of organic dye materials as functions of the wavelength λ. The optical constant of a material is the complex refractive index $\tilde{n} = n + i.k$. In the first embodiment of the invention, the wavelength λ equals 655 nm and either an AZO dye material with a real part n_{R1} of the refractive index approximately equal to 2.3 or a cyanine dye material with a real part n_{R2} of the refractive index equal to 2.2 is used. When data are recorded into the recording layer, the refractive index falls to approximately 1.6.

Fig. 5 shows the modulation as a function of the product of the refractive index variation and the thickness of the first recording layer. For DVDs, the modulation is expected to remain greater than 0.6. For other applications, values lower than 0.6 may be acceptable.

It turns out that choosing a first recording layer L_0 with a thickness $\Delta n_R.d_R$ greater than 0.06.λ guarantees a modulation value above 0.6.

Fig. 6 shows a diagram indicating jitter measurements of data read back from the second recording layer L_1 through the partially recorded recording layer L_0. Gray bands indicate the radii of the optical disk for which data have been recorded on the first recording layer L_0.

In optical disks, data are encoded in the lengths of pits and of the unrecorded areas that are in between the pits, also called spaces, that are recorded on the disk. It should be noted that the actual recording of marks does not necessarily take place in the groove G but may take place in the area L between grooves, also referred to as lands. On this case the guide groove G merely serves as a servo tracking means with the actual radiation beam recording spot being present on the land.

A length should be an integer multiple of a predefined channel bit length. For example, the predefined channel bit length equals 146.7 nm for a dual-layer density DVD. Since it is not possible to record such a length precisely, an evaluation of the error made in the recording of the lengths is highly needed.

A possible measurement of such an error is provided by the jitter. The jitter is defined as the width of the distribution of the leading and trailing edges of the pits and spaces with respect to the expected or ideal positions of these edges, which is given by the predefined channel bit length. What is actually measured in the experiments is the distribution in timing errors of the leading and trailing edges of the signals coming from the disk during read-out with respect to the expected timing. Said timing is given by the ratio of the bit length and the read velocity. The average jitter curve 30 shows that the recording of the first recording layer L_0 of an optical storage medium according to the invention only causes a small increase of the jitter values, which corresponds to only small deteriorations of the conditions for reading the second recording layer L_1.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs places between parentheses shall not be construed as limiting the claims. The word "comprising" does not exclude the presence of elements or steps other than those listed in a claim. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

CLAIMS

1. An optical storage medium comprising below an entrance face (EF) a higher recording stack (ST_0) comprising a higher recording layer (L_0) having a thickness d_R and a refractive index n_R and at least a lower recording stack (ST_1), said lower recording stack (ST_1) being recorded or read back by a radiation beam (4) entering the optical storage medium through the entrance face (EF) with a wavelength (λ), focused on said lower recording stack (ST_1), and transmitted through the higher recording stack (ST_0), a recording of the higher recording layer (L_0) causing an optical thickness variation $\Delta(n_R.d_R)$ between recorded and unrecorded areas of said first recording layer (L_0), which lies within the range $[0.03\lambda, 0.125\lambda]$.

2. An optical storage medium according to claim 1, wherein said higher recording layer (L_0) comprises an organic dye material.

3. An optical storage medium according to claim 1, wherein said higher recording stack (ST_0) comprises a thin metal reflector layer (M_0).

4. An optical storage medium according to claim 1, wherein said lower recording stack (ST_1) comprises a lower recording layer (L_1) comprising an organic dye material and a thick metal reflector layer (M_1).

5. An optical storage medium according to claim 1, wherein said wavelength (λ) is approximately equal to 655 nm.

6. An optical storage medium according to claim 5, wherein said optical storage medium has the DVD format.

7. An optical storage medium according to claims 1 and 6, wherein said higher recording layer (L_0) has a thickness (d_R) which is greater than 28 nm and less than 116 nm.

8. An optical storage medium according to claim 1, wherein said thin metal layer (M_0) has a thickness (d_{M0}) which is greater than 5 and less than 25 nm and is made of a silver alloy.

9. An optical storage medium according to claim 1, comprising below the entrance face (EF) a transparent substrate (1) having a thickness (d_1) which is greater than 0.3 and less than 1.2 mm.

10. A method of manufacturing an optical storage medium, comprising a higher recording layer (L_0) and at least a lower recording layer (L_1), said higher recording layer (L_1) being recorded or read back by means of a focused radiation beam with a wavelength (λ), said method of manufacturing comprising the steps of:
    - Forming a pre-grooved semi-transparent substrate (1),
    - Depositing an organic dye onto the pre-grooved substrate (1) for forming the higher recording layer (L_0), such that a recording of said higher recording layer (L_0) causes an optical thickness variation between recorded and unrecorded areas of said first recording layer (L_0), which lies within the range $[0.03\lambda, 0.125\lambda]$.

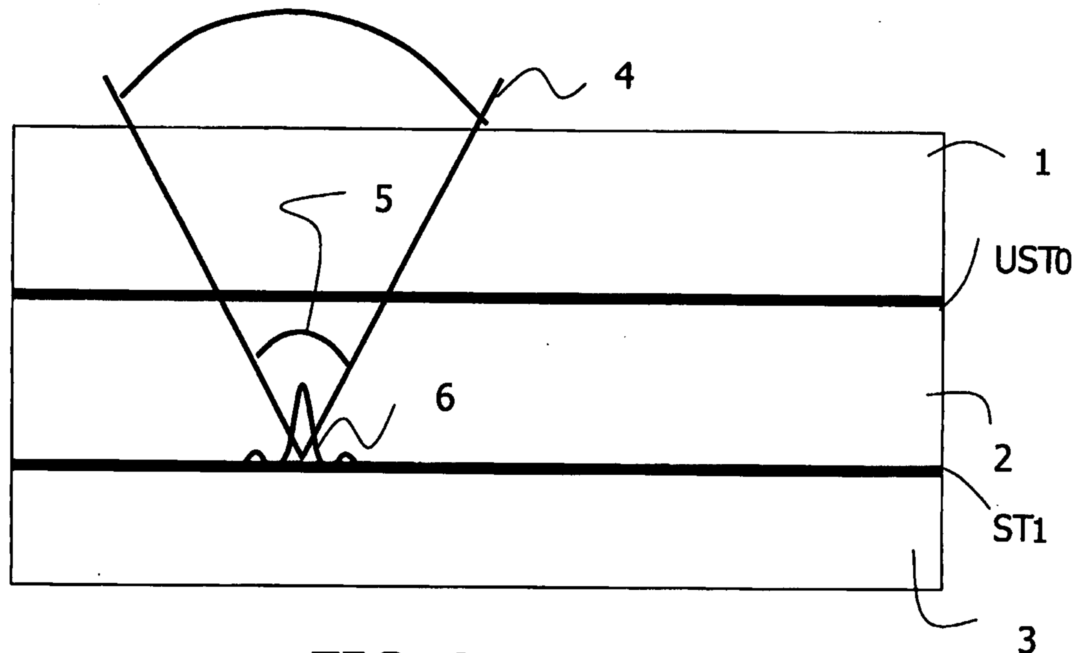

FIG. 1a

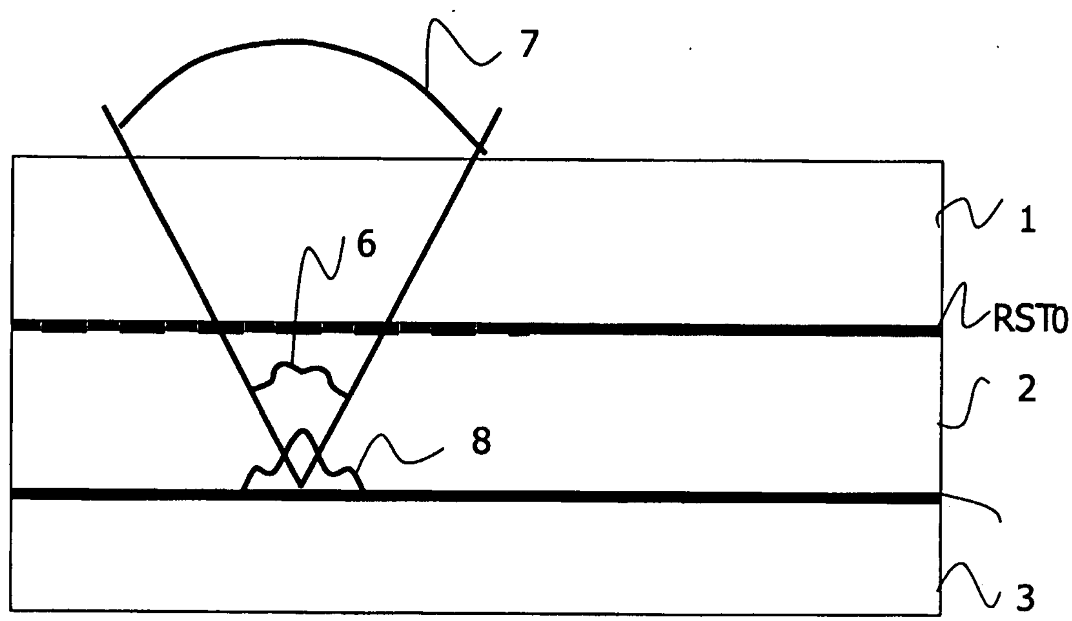

FIG. 1b

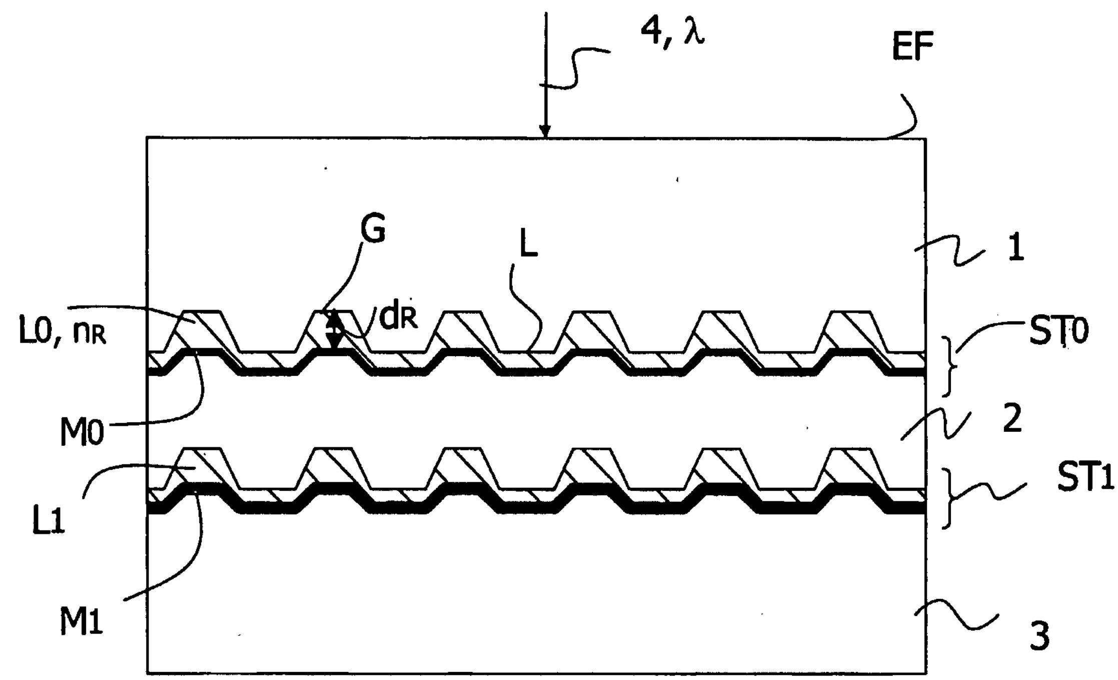

FIG. 2

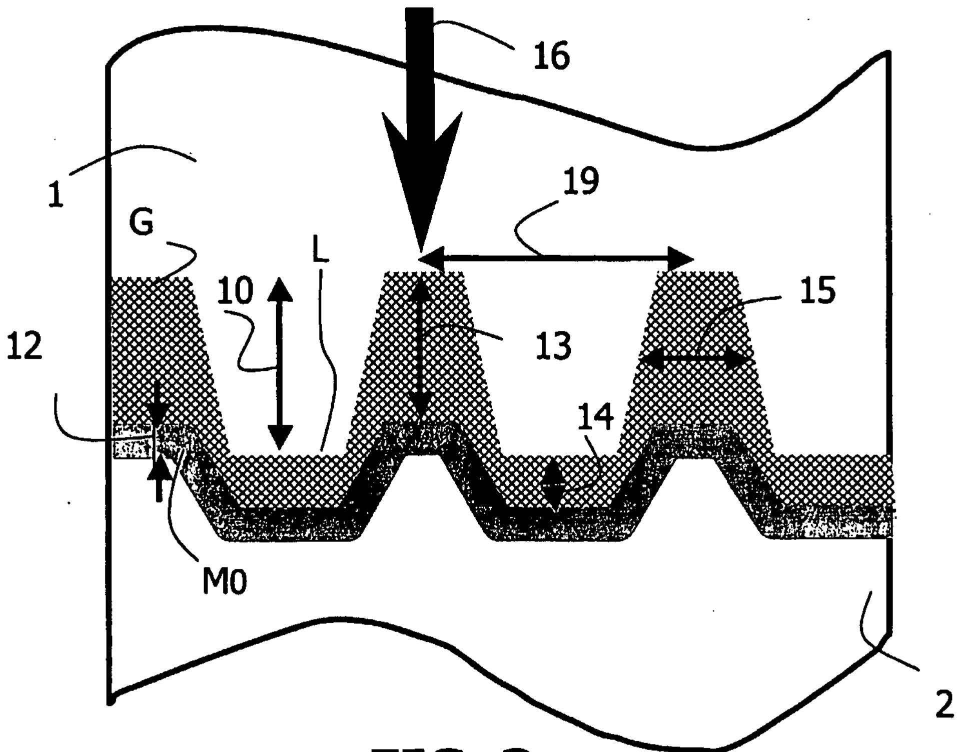

FIG. 3a

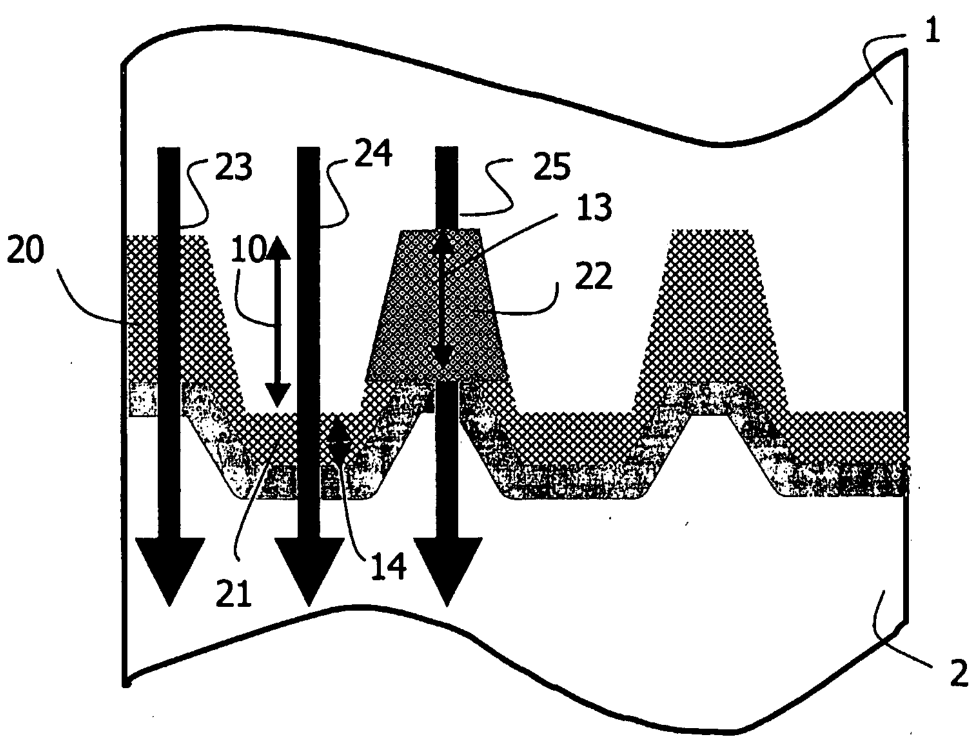

FIG. 3b

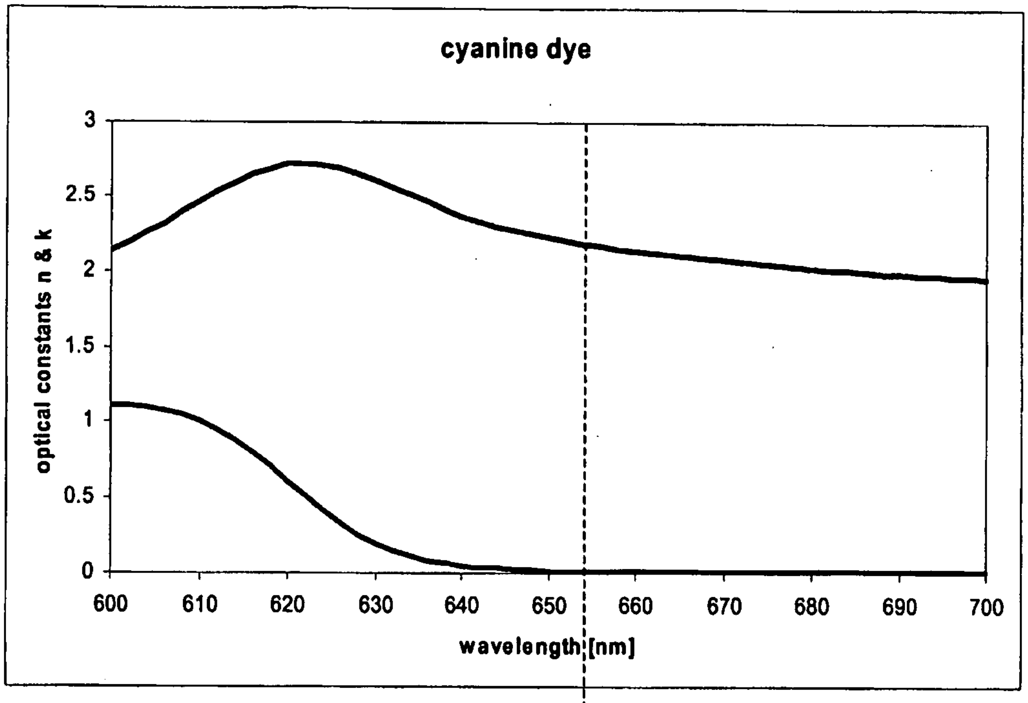
cyanine dye
optical constants n & k
3
2.5
2
1.5
1
0.5
0
600
610
620
630
640
650
660
670
680
690
700
wavelength [nm]

FIG. 4a

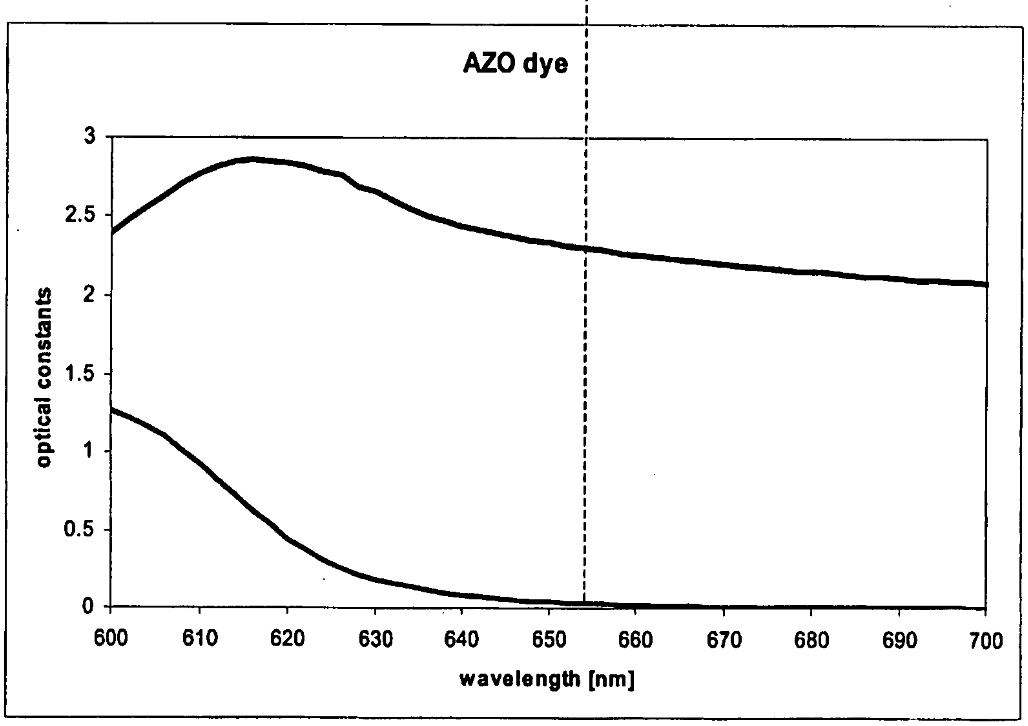
AZO dye
optical constants
3
2.5
2
1.5
1
0.5
0
600
610
620
630
640
650
660
670
680
690
700
wavelength [nm]

FIG. 4b

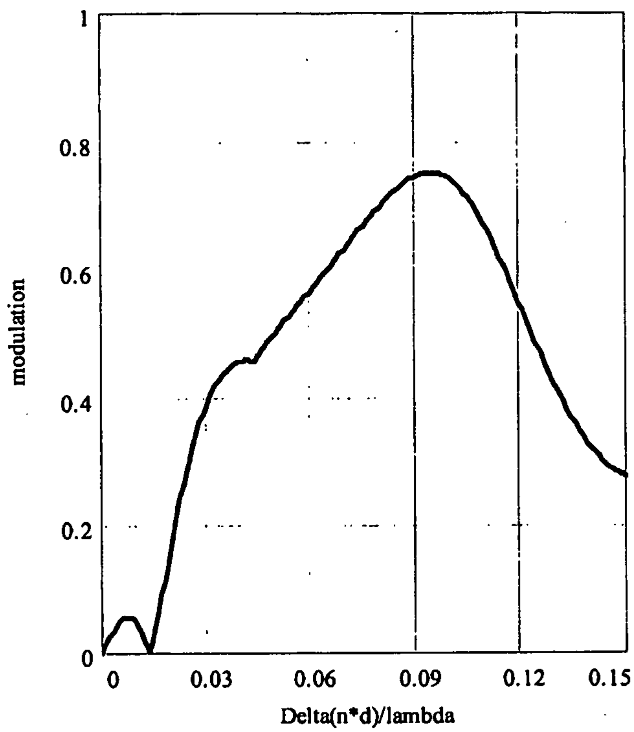

FIG. 5

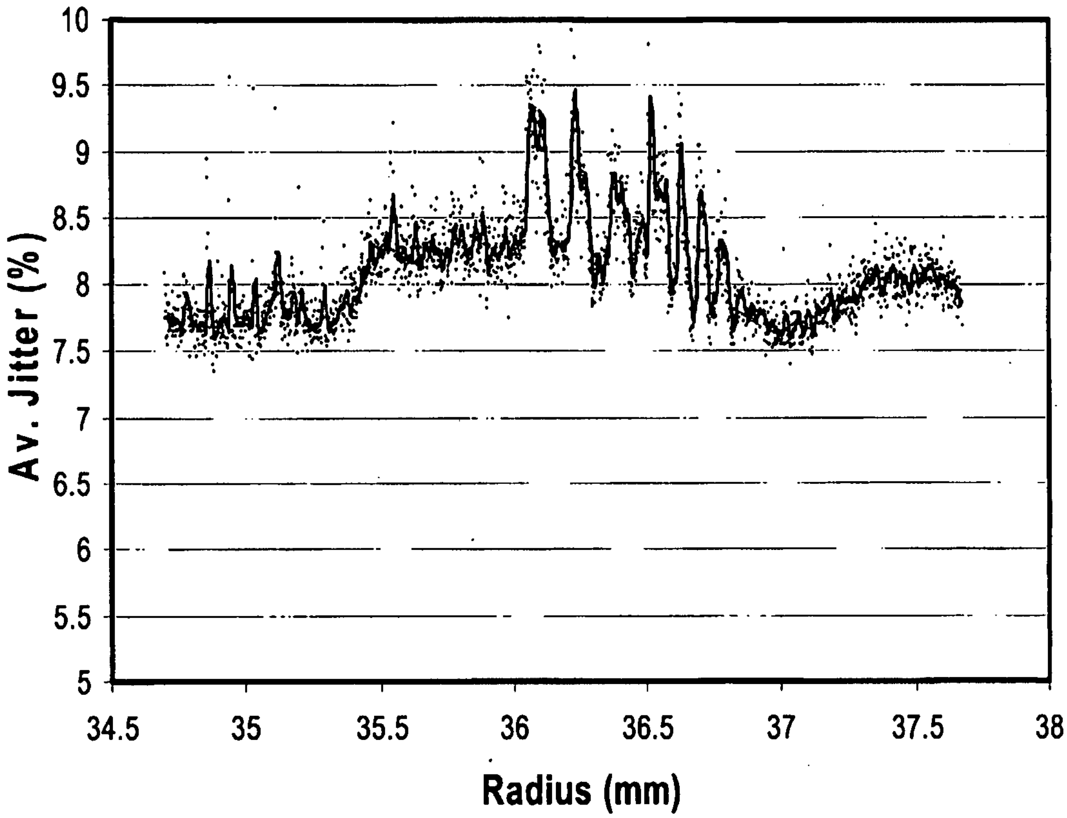
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
Av. Jitter (%)
34.5
35
35.5
36
36.5
37
37.5
38
Radius (mm)

FIG. 6

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IB2004/001710

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G11B7/24 G11B7/26

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G11B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

PAJ, WPI Data, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 September 2004	11/10/2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Hermann, R

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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